2012 Southern California Earthquake Center Annual Report
Continuing Study of Tremor in Central and Southern California

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Summary

A systematic analysis of deep tectonic tremor in California not only provides important new information on the fault mechanics on the deep extension of the crustal faults but also may shed new light on the predictability of large earthquakes. Our past year's effort mainly focused on the following two directions: (1) continuing study of triggered tremor in central and southern California; (2) comparisons between triggered earthquakes and tremor in California.

1. Continuing study of triggered tremor in central and southern California

Numerous cases of triggered tremor along the San Andreas Fault (SAF) in central California has been well documented [e.g., Gomberg et al., 2008; Peng et al., 2009]. In comparison, Chao et al. [2012] showed that only the 2002 Mw7.9 Denali Fault earthquake has triggered clear tremor along the San Jacinto Fault (SJF) in Southern California. Because both regions have similar high-quality borehole instruments, the lack of triggered tremor in Southern California suggests that the ambient conditions along the SJF are not in favor of tremor generation. This is also consistent with a relative lack of ambient tremor in that region.

The 2011 Mw9.0 Tohoku, Japan, earthquake triggered deep tectonic tremor and shallow microearthquakes in numerous places worldwide. Chao et al. [2013] conducted a systematic survey of triggered tremor in regions where ambient or triggered tremor has been previously identified, including the three regions in California. Not surprisingly, we found clear triggered tremor in

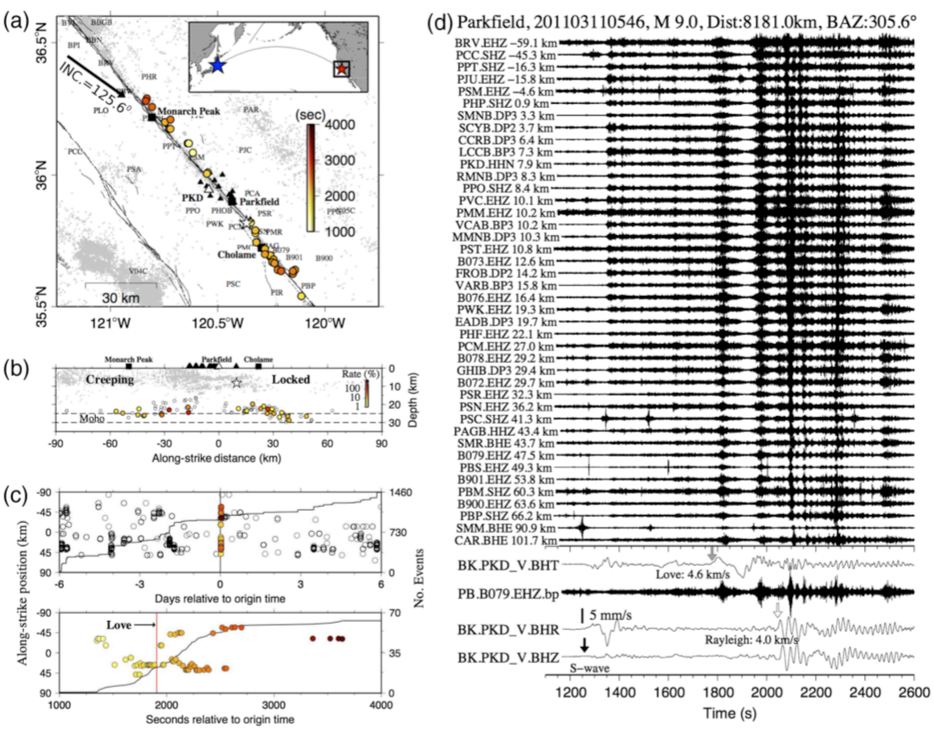
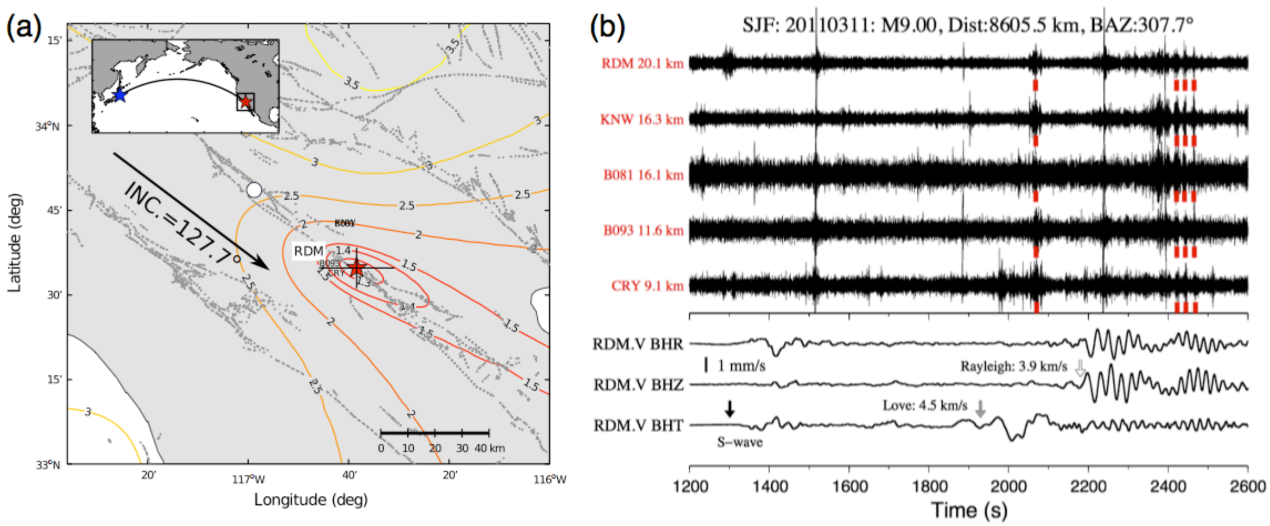


Figure 1. Triggered and ambient tremor along the Parkfield-Cholame section of the San Andreas Fault (SAF). **(a)** Map of triggered tremor during the Tohoku mainshock. **(b)** An along-fault cross-section view showing the depth profile of the 88 tremor locations and background earthquakes. **(c)** (top) Along-strike distances versus the number of tremor occurrences. (bottom) A zoom-in plot around the teleseismic waves of the mainshock. **(d)** The 2-8Hz band-pass filtered seismograms showing the moveout of triggered tremor at multiple sources. The bottom three traces show the instrument-corrected broadband velocity seismograms at station BK.PKD.

the Parkfield-Cholame section of the SAF in central California, starting with the S wave, and continued during the Love and Rayleigh waves [Hill et al., 2013]. As shown in Figure 1, a weak tremor burst was first triggered at ~1,400 s by the arrival of an S wave and the tremor source was located in the creeping section of the SAF, northwest of station PKD. A weak tremor burst triggered by the SHSH wave (e.g., an SH wave reflected by the Earth's surface midway between the epicenter and Parkfield) at ~1,600 s was located beneath the hypocenter of the 2004 M_w6.0 Parkfield earthquake. The Love wave triggered two tremor bursts near Cholame, at about 1,800 s and 1,950 s, respectively. The subsequent Rayleigh waves also triggered multiple tremor sources scattered in both the creeping section of the SAF and around Cholame. We further examined ambient tremor six days before and after the Tohoku mainshock. As shown in Figure 1b, clear tremor episodes occurred 2, 4, and 6 days before the Tohoku mainshock, and tremor activity clearly increased during the teleseismic waves and in the first few hours afterward. However, we did not find any significant changes in tremor activities a few days after the mainshock.

No evidence of triggered tremor was found in the Calaveras Fault in northern California. Interestingly, we observed weakly triggered tremor along the SJF in southern California. As shown in Figure 2, tremor signals are best shown in the horizontal component with a frequency range of 4-10Hz. The first tremor burst occurred during the Love wave at ~2,050 s. Additional tremor bursts occurred between 2,350 s and 2,550 s during the later arriving Rayleigh waves. In addition, a local earthquake occurred at ~2240 s during the first few cycles of the Rayleigh waves. The tremor during the Tohoku surface waves was located in the Anza section of the San Jacinto Fault, about ~36km southeast of the tremor source triggered by the Denali Fault earthquake [Gomberg et al., 2008].



ne single triggered tremor source during the Tohoku earthquake. **(b)** The 4-10Hz band-pass filtered seismograms in the N-component showing the moveout of triggered tremor. The bottom three traces show the instrument-corrected broadband velocity seismograms at station AZ.RDM.

Figure 3 shows that the surface wave amplitudes and pre-event background noises in these two regions are similar, yet the triggered tremor amplitudes differ by nearly an order of magnitude. This is consistent with our previous results [Chao et al., 2012], suggesting that that such difference could be related to different ambient tremor rate or tremor triggering threshold in these regions.

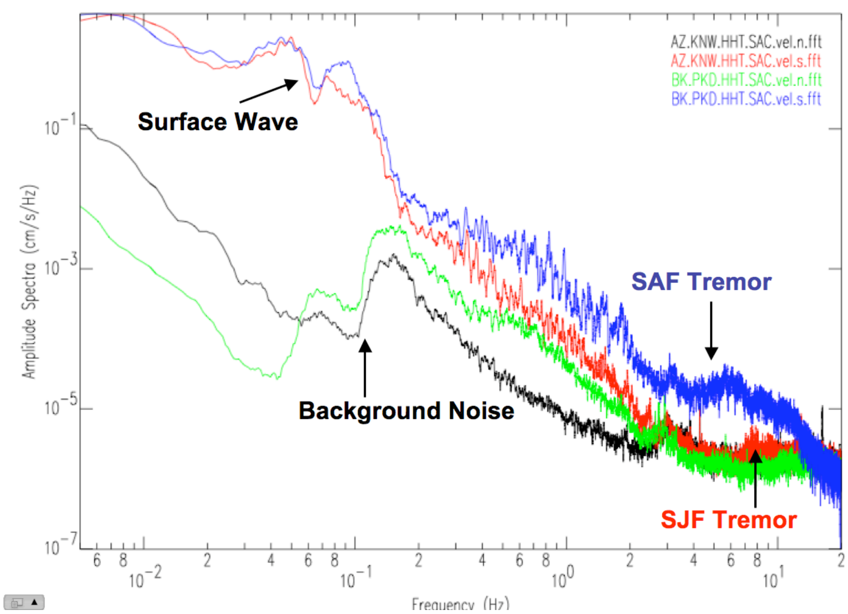


Figure 3. A comparison of the amplitude spectra computed from the transverse component seismograms recorded at station PKD in Central California (blue) and station KNW in Southern California (red) during the large-amplitude surface waves. The green and black lines denote the spectra before the mainshock for station PKD and KNW, respectively. Despite similar amplitudes for the long-period surface waves, the amplitudes in the tremor band of 2-10 Hz are quite different for these stations.

2. Comparisons between triggered earthquakes and tremor in California

Aiken et al. [2013] conducted a systematic comparisons among triggered earthquakes in three geothermal regions in California (Long Valley, Coso, and Geysers), and triggered tremor along the Parkfield-Cholame section of the SAF. In each of these regions, we examine waveforms from regional and teleseismic earthquakes that occur during the 2000-2012 period. We band-pass filter the waveforms and compute β-statistics from hand-picked local earthquakes to confirm the significance of our findings. We find that the LVC is the least responsive and has an apparent dynamic stress threshold above 10 KPa. On the other hand, the Coso and Geysers geothermal fields are more responsive to surface waves of distant earthquakes. However, deep tectonic tremor along Parkfield-Cholame section of the SAF appears to be most stress sensitive, and respond to teleseismic waves with dynamic stresses as low as 0.5 KPa. While at least part of this discrepancy could be explained by different quality of seismic networks in each region, we argue that the higher sensitivity of deep tremor is generally consistent with laboratory observations of lower triggering threshold of tremor as compared with regular earthquakes [Bartlow et al., 2012]. We are still in the process of understanding the physical causes of apparent variations of triggering in the three geothermal regions.

Student Support and Involvement. This project provided partial support for the GT graduate student Kevin Chao, who finished his Ph.D. in May 2012, and is now working as a postdoc fellow in ERI, University of Tokyo. The remaining funding is used to support research scientist, who is currently examining tremor in the Simi Valley and the San Gabriel fault. It also provide partial support for a summer intern Gregory Armstrong (Georgia State undergraduate student) in summer 2012. Gregory has conducted a systematic search of triggered tremor in Cuba [Peng et al., 2013] and southern Chile. He also presented his work at the 2012 SCEC annual meeting [Armstrong et al., 2012]. Unfortunately, he did not continue this work since fall 2013. We will hire three new SCEC interns to continue to study tremor in California and elsewhere around the world. These SCEC interns will be trained to conduct scientific research in the frontier of seismology. Such effects are valuable in attracting talented undergraduate students into the pipeline and preparing them for future challenges in the field of seismology.

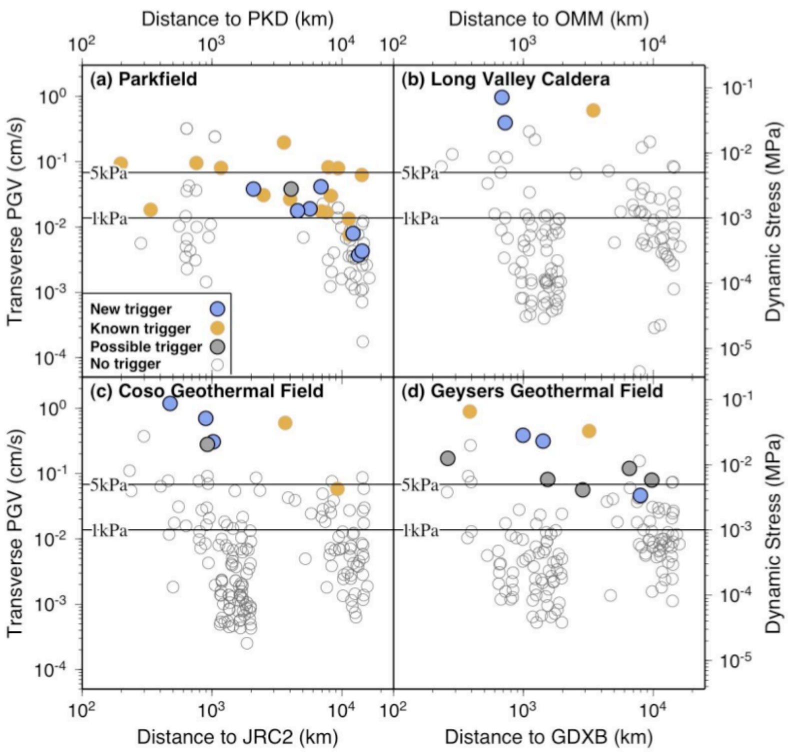


Figure 4. A comparison of transverse peak ground velocities (PGVs) and the associated dynamic stresses measured at Parkfield (a), Long Valley Calderea (b), the Coso (c) and Geysers geothermal fields. The horizontal lines mark the dynamic stresses of 1 and 5 kPa. The blue, yellow, gray circles mark the newly identified triggering, known triggering, and possible triggering events.

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